Featuring of Silicon Carbide and Boron Nitride on Functional Behaviour of Magnesium Alloy (Az91e) Composites Through Liquid Stir Casting Process

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Abstract: This work investigates the effects of two nanoassistances on the microstructural, mechanical and thermal performance of AZ91E alloy composites made by liquid stir casting namely silicon carbide and boron nitride. To assess density, porosity, tensile performance and thermal stability different levels of reinforcement were systematically applied. Tensile strength and resistance to thermal degradation were considerably increased as a result of the gradual decrease in porosity and enhanced particle dispersion brought about by the use of hybrid reinforcements. When equated to the non reinforced alloy the optimized hybrid design showed a delayed onset of thermal degradation by over 56 °C and an improvement in ultimate tensile strength of around 24%. These enhancements demonstrate how SiC and BN work in concert to improve load-bearing capability and high-temperature endurance. For next generation lightweight automotive structural applications that demand a better strengthtoweight ratio, thermal reliability and decreased susceptibility to defect the developed AZ91E/SiC/BN composites show great promise.

# Introduction

The automotive industry makes extensive use of magnesium alloys especially those in the AZ91 series because of its exceptional castability, high specific strength and low density. Wider usage is constrained by their very low mechanical strength and thermal stability. Ceramic nanoparticles like boron nitride and silicon carbide can be added as reinforcements to get around these restriction and whereas BN improves wear resistance and thermal stability SiC increases hardness and load bearing capability [1-4].

Metal matrix composites (MMCs) based on magnesium and aluminum continue to get a lot of research interest because of their enhanced strength resilience to wear and lightweight characteristics and aluminum MMCs were thoroughly examined [5-9], who found that they performed better mechanically and tribologically than traditional alloys. AI optimized hybrid MMCs reinforced with AlO₃, graphite and bauxite residue showed exceptional tribological and machining performance, especially for brake hub applications as shown by Karthick and Bharathiraja [2]. In their assessment of stir cast AA6061 composites, Itwasemphasized the technique adaptability in adjusting reinforcement dispersion and overall mechanical behavior [10-12].

Additionally, the significance of nanoscale reinforcements has been highlighted. In their critical analysis of the reinforcing philosophy for magnesium nanocomposites, emphasized the advantages of nano-additions in terms of tribological properties and corrosion resistance [13-16]. In a similar vein, reviewed stir-cast aluminum MMCs highlighting their wear properties and strengthening methods and by creating high performance magnesium hybrid nanocomposites containing AlO₃ and MoS₂ nanoparticles [17-19]. This knowledge and simultaneously improved their lubricating and strength capabilities. A more comprehensive overview of MMCs and their engineering uses was providedhighlighting their applicability in the automotive, aerospace and biomedical industries [20-22].

The adaptability of nanoparticles in improving tensile and thermal properties even in polymer matrices was demonstrated investigation of epoxy nanocomposites reinforced with MgO and BN which went beyond metallic systems [20-22]. Using stir casting, investigated magnesium-based nanocomposites, emphasizing increases in hardness and wear resistance [23-25]. In their discussion of aluminum MMCs' present and potential futures, predicted that hybrid reinforcements will predominate in next-generation applications [26].

These assertions have been further validated by experimental research. After analyzing AZ31/SiC composites under thermal cycling, reported stable mechanical and microstructural integrity. Stir-cast AA6061–SiC composites were described [27-29] who confirmed that consistent particle dispersion results in improved wear resistance. In order to elucidate strengthening mechanisms,] used models and experiments to create hybrid aluminum composites reinforced with zirconia and carbon nanotubes [30-32].

Hybridization has been very successful. Al–SiC–WC composites were created [33] Using stir casting and they discovered significant increases in corrosion and wear resistance. Similar to this, examined reinforcement techniques in aluminum MMCs and came to the conclusion that tribological results are greatly influenced by the type of reinforcement used (ceramics, carbides) [34-36].

In order to enhance functional behavior for automotive structural applications and this study focuses on creating AZ91E based nanocomposites reinforced with SiC and BN via liquid stir casting.

# Materials and Methods

## Materials

The strong strengthtoweight ratio, resistance to corrosion and exceptional castability of AZ91E magnesium alloy ingots led to their selection as the matrix material. Powdered boron nitride and silicon carbide nanoparticles were employed as reinforcements. Before being incorporated the reinforcements were heated to 300 °C to improve wettability and reduce moisture induced flaws [37-39].

The process of liquid stir casting was utilized to fabricate the composites. To avoid oxidation and burning losses, the AZ91E alloy was first melted at 720 °C in a protective argon + SF₆ environment. The warmed SiC and BN nanoparticles were added progressively after the melt had ventilated to a semi solid state (around 600 °C). To encourage even scattering and robust interfacial adhesion mechanical stirring was done for ten minutes at 500 rpm. In order to guarantee flawless solidification and decreased porosity in the cast composites and the molten slurry was lastly poured keen on steel molds that had been heated [40-43].

## Composite Formulations

To investigate the influence of hybrid reinforcements in a methodical manner and four diverse composite inventions were created. The unreinforced reference was the base material magnesium alloy AZ91E and to improve the strength and hardness of two weight percent SiC nanoparticles were added to the second configuration. In order to assess the synergistic impact of dual reinforcement on mechanical and thermal properties the third and fourth formulations blended 2 weight percent SiC with a weight percent and 3 weight percent BN. This stepwise methodology enables a comparative examination of both single. Hybrid reinforcement effects on the AZ91E matrix [44-49].

**TABLE 1.** Composite Configurations Table

|  |  |
| --- | --- |
| **Tial ID** | **Composition** |
| Tial 1 | AZ91E (Unreinforced) |
| Tial 2 | AZ91E + 2 wt% SiC |
| Tial 3 | AZ91E + 2 wt% SiC + 1 wt% BN |
| Tial 4 | AZ91E + 2 wt% SiC + 3 wt% BN |

Archimedes' principle was employed to evaluate the density and porosity of the composites, assuring an accurate assessment of matrix integrity and particle distribution. Using machined specimens to estimate ultimate tensile strength and ductility tensile behavior was characterized in conformity with the ASTM E8 standard and the thermogravimetric analysis in a nitrogen atmosphere was employed to test thermal stability allowing for the tracking of the onset of deterioration and residual mass at high temperatures and the manufactured AZ91E/SiC/BN composites were reliably and reproducibly characterized thanks to these standardized testing methodologies [50].

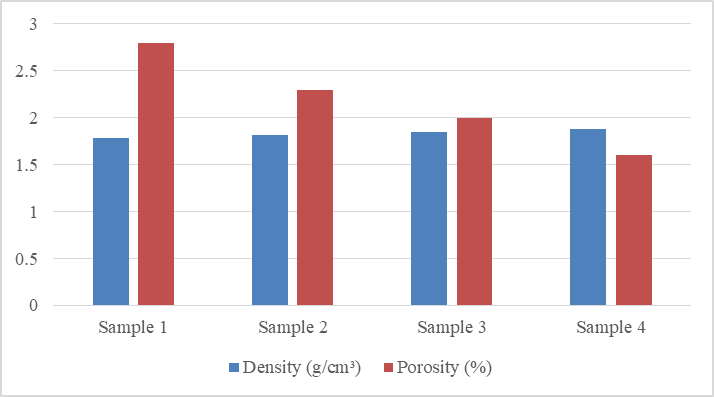
# Results and Discussion

## Density and Porosity

The density of the composites progressively rose with the introduction of nano SiC and BN reinforcements going from 1.78 g/cm³ for the unreinforced alloy to 1.88 g/cm³ at the highest hybrid loading. Porosity dropped from 2.8% to 1.6% demonstrating better wettability and effective particle packing within the matrix. The combined effect of SiC’s greater density and BN’s fine dispersion capacity led to minimizing voids. Improved structural integrity revealing that hybrid reinforcement efficiently promoted uniform distribution and decreased casting related flaws.

**TABLE 2**Density and Porosity

|  |  |  |
| --- | --- | --- |
| **Specimen** | **Density (g/cm³)** | **Porosity (%)** |
| Tial 1 | 1.78 | 2.8 |
| Tial 2 | 1.82 | 2.3 |
| Tial 3 | 1.85 | 2.0 |
| Tial 4 | 1.88 | 1.6 |



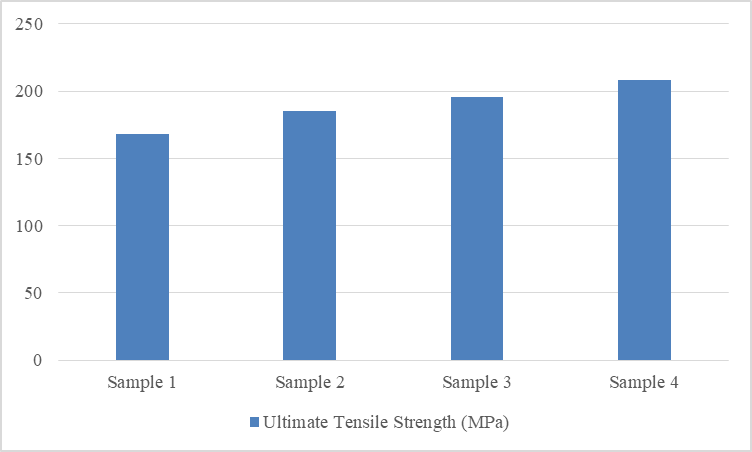
**Figure 1.**Microhardness

## Tensile Strength

The accumulation of nano SiC and BN reinforcements controlled to a substantial upsurge in the tensile behavior of AZ91E. The ultimate tensile strength improved progressively from 168 MPa in the base alloy to 208 MPa in Tial 4, equivalent to an improvement of about 24% and this strengthening effect is due to grain refinement, effective load transfer from the matrix to the hard particles, and the synergistic impact of BN in preventing dislocation mobility. A steady drop in elongation from 5.8% to 4.6% with increasing reinforcement content demonstrating the ductility trade-off associated with the existence of hard ceramic phases. The hybrid composite displayed the optimum balance of tensile strength and acceptable ductility making it highly suitable for structural applications needing both load bearing capacity and lightweight design.

**TABLE 3.** Tensile Strength

|  |  |  |
| --- | --- | --- |
| Specimen | Ultimate Tensile Strength (MPa) | Elongation (%) |
| Tial 1 | 168 | 5.8 |
| Tial 2 | 185 | 5.2 |
| Tial 3 | 196 | 4.9 |
| Tial 4 | 208 | 4.6 |



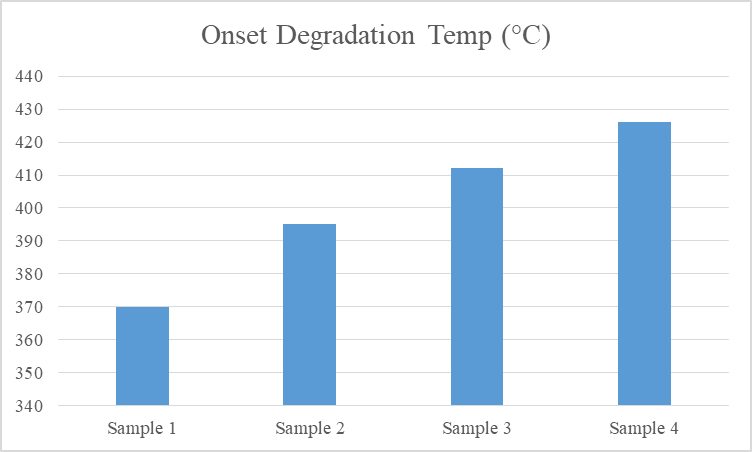
**Figure 2.**Tensile Strength

## Thermal Stability

The thermal stability of the AZ91E composites improved consistently with the introduction of nano SiC and BN reinforcements.The onset degradation temperature increased from 370 °C in the base alloy to 426 °C demonstrating a considerable boost in resistance to thermal decomposition. The residual mass percentage increased from 8.2% to 12.4%, showing less mass loss after heating. This enhancement is mainly related to the strong thermal resistance of BN particles to function as an efficient barrier against oxidation and delay the onset of degradation while SiC contributes to stable heat conduction and uniform thermal distribution. Among the evaluated specimens, the hybrid composite comprising 2 wt% SiC and 3 wt% BN provided the most pronounced thermal stability, demonstrating its potential for high temperature service conditions in automotive and aerospace applications.

**TABLE 4.** Thermal Stability

|  |  |  |
| --- | --- | --- |
| Specimen | Onset Degradation Temp (°C) | Residual Mass (%) |
| Tial 1 | 370 | 8.2 |
| Tial 2 | 395 | 10.5 |
| Tial 3 | 412 | 11.8 |
| Tial 4 | 426 | 12.4 |



**Figure 3.** Thermal Stability

# Applications in Automotive Structures

The AZ91E/SiC/BN hybrid composites displayed considerable increases in tensile strength thermal resistance and microstructural stability while simultaneously obtaining decreased porosity levels and these combined qualities make them particularly ideal for lightweight automobile structural components such as gearbox housings engine brackets and support frames. Their low density coupled with better load bearing capacity and resistance to thermal deterioration, provides consistent performance under changing dynamic stresses and elevated operating temperatures typically observed in automotive settings. The increased mix of strength-to-weight ratio and durability puts these composites as potential alternatives to standard alloys for next generation vehicle designs focusing on efficiency performance and sustainability.

# Conclusion

The inclusion of nano SiC and BN reinforcements into AZ91E magnesium alloy by the process of liquid stir casting resulted in considerable improvements in terms of mechanical performance, decrease in porosity, and thermal stability and out of all the combinations, Tial 4 of 2 weight % SiC and three weight % BN demonstrated the most balanced augmentation. It achieved around 24 percent greater tensile strength a significant reduction in porosity and an improvement in thermal endurance. The findings presented here highlight the promise of AZ91E/SiC/BN composites as materials that are environmentally friendly, lightweight and high performing for structural applications in the next generation of automobile architecture.

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